Remote Sensing-Based Analysis of Potential Epithermal Gold Mineralization in the Sunda Arc Region of Bogor Regency

Silmi A.A. [1*], Nikolas A.P.P.[2], Shafira H.[1],

[1]Geographic Information Science, Faculty of Social Science Education, Universitas Pendidikan Indonesia, Bandung, 40143, Indonesia

[2]Mapping Survey and Geographic Information, Faculty of Social Science Education, Universitas Pendidikan Indonesia, Bandung, 40143, Indonesia

*aliyan.silmi@upi.edu (*Corresponding author's email only)

Abstract The Sunda magmatic arc that passes through the island of Java has played a role in the formation of gold deposits, particularly in the formation of low-sulfidation epithermal deposits in the Pongkor region, Bogor Regency. Currently, PT Antam Tbk. through its Gold Mining Business Unit (UPBE) manages an underground gold mine that produces pure gold and silver as its main products. Since 2016, UPBE Pongkor has experienced a decline in gold ore production, and various efforts have been made to explore and produce gold ore. Remote sensing technology, with the utilization of multispectral imagery, was used in this study to detect suspected zones of potential epithermal gold mineralization. This study used several geological indicators related to epithermal gold formation, such as the presence of propylitic and agrilic alteration minerals, lineament, and lithological characteristics. The processing techniques used in this study were Sabin's Ratio algorithm and Crosta's Directed Principal Component Analysis (DPCA). Both techniques were used to obtain information on the presence of surface minerals resulting from hydrothermal alteration, such as chlorite and smectite-illite minerals. This study integrates the indicators using the weight of evidence (WOE) method. The results of the study indicate that the presence of chlorite minerals is positively associated with the presence of gold deposits in the mining business permit (IUP) area of UBPE PT. Antam Pongkor has a value of 0.1492. The presence of lineaments is positively associated with gold deposits, with a value of 0.4726 at the lineament buffer class value of 0-100 meters. While the lithology of volcanic rocks is positively associated with gold deposits at values of 0.4760 and 0.3486. The results of the analysis show that epithermal gold deposits in Bogor Regency are associated with propylitic alteration types, with a distance buffer from the lineament of 0-100 meters, and are found in volcanic rocks in the form of basalt, andesite, and tuff. This association shows the distribution of suspected zones of potential epithermal gold mineralization in 5 areas around Bogor Regency, namely Parung Panjang, Cigudeg, and Jasinga sub-districts.

Keywords: *Remote Sensing*, *Epithermal Gold Deposit*, *Sabin's Ratio*, *Crosta's Directed PCA*, *Weight of Evidence*

Introduction

Based on commodity type, West Java's metal mineral potential is divided into: gold, silver, copper, zinc, lead, iron sand, manganese, and titanium sand. These resources are spread across several regencies in West Java, and generally have been mined, are currently being mined, or are still in the exploration stage, including Bogor Regency (Rosana, Denni, & Wawan, 2011). Gold and silver mining activities in Bogor Regency are carried out by the Pongkor Gold Mining Business Unit (UBPE) of PT Antam Tbk, which based on the results of its annual report on primary gold production shows a downward trend in ore content (Zafar, Yudhistira, & Hoppy, 2019).

Efforts to determine the location of suspected potential epithermal gold mineralization in Bogor Regency are ongoing. This is related to Regional Regulation No. 7 of 2022, Chapter V, Article 6, paragraph (2), which stipulates that mining planning is carried out by determining zones, areas, and reserve areas for potential mining materials. In Bogor Regency, this regulation is relevant to the gold potential around Mount Pongkor, which needs to be integrated into the RTRW (Regional Spatial Plan) to avoid conflict with the Halimun-Salak protected area and its ecological functions. Thus, gold exploration and development in Bogor must be based on spatial planning that balances economic interests and environmental sustainability (Perda No. 7/2022; PP No. 25/2023; RTRW Kabupaten Bogor 2024).

Mapping of suspected gold potential zones was conducted using a remote sensing approach, this was done to reduce costs, energy, and relatively high time. This study utilized Landsat 9 and ASTER satellite data in an effort to identify epithermal gold potential in Bogor Regency. It was used to obtain lineament data related to structural zones, data on the distribution of hydrothermal alteration zones using the Sabin's Ratio and Crostal's Directed Principal Component Analysis (DPCA) methods, and identification of rock types found in potential gold mineralization locations. Geological features that can be obtained from remote sensing to search for gold potential consist of three aspects: lithology, structure, and hydrothermal alteration. These three aspects are associated with the presence of gold deposits (Franandy & Isniarno, 2023).

Literature Review

The research was conducted in Bogor Regency, West Java, located between 106º23'45” – 107º13'30” East Longitude and 6º18'0” – 6º47'10” South Latitude.

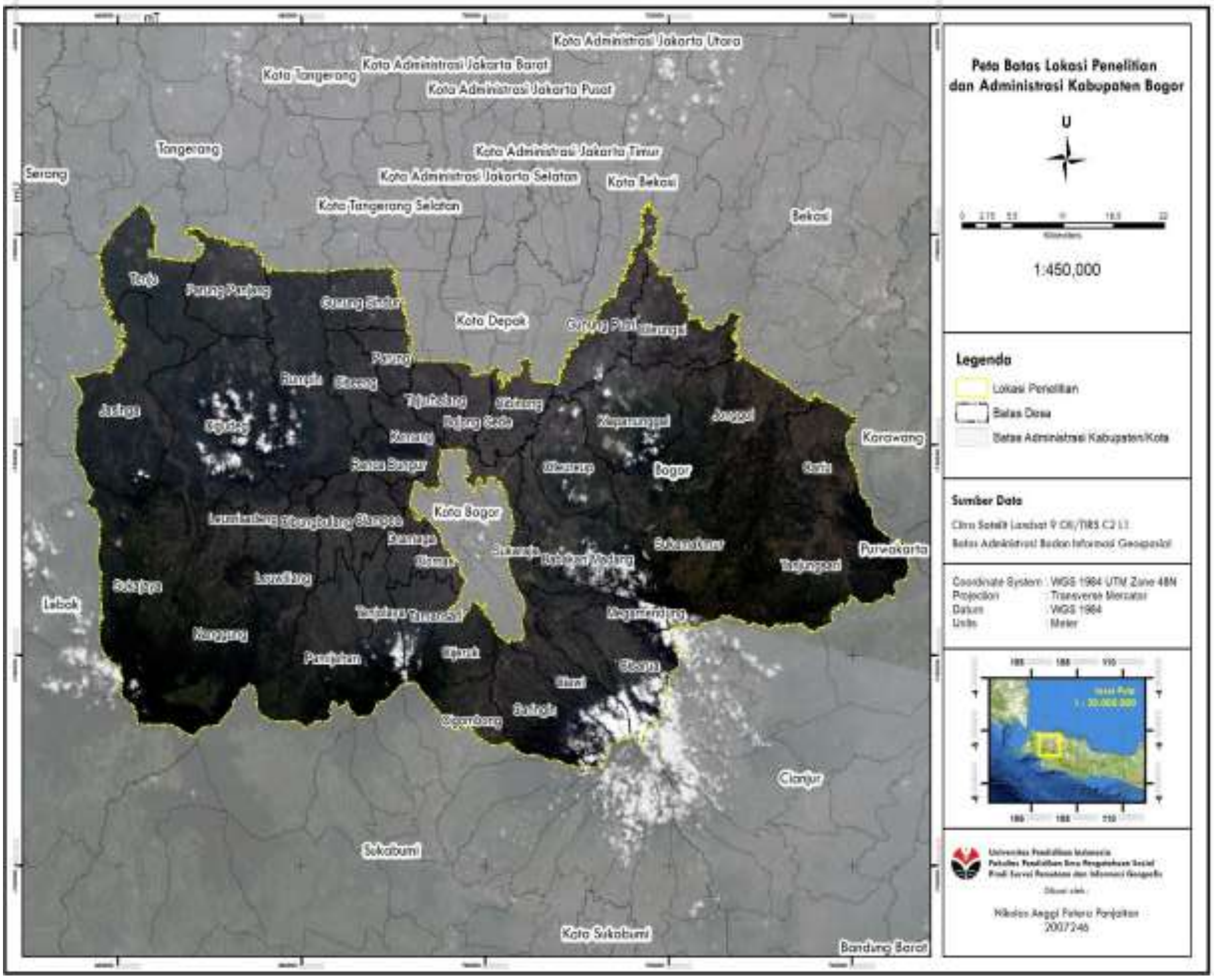

Figure 1: Research Area

Geological Setting

Bogor Regency has a diverse geological composition but can be separated by location, such as volcanic deposits of the Quaternary and Tertiary periods are widely distributed on the western side of Bogor Regency, which are very few can be found in the eastern part. There are five rock formations that make up the study area, from oldest to youngest, Jatiluhur Formation (Tmj), which consists of sandstone and clay shale inserts, with an age of Early Miocene. The upper part of this formation fingers the Klapanunggal Formation. The Klapanunggal Formation (Tmk) consists of dense reef limestone containing large foraminifera and other fossils, is of Early Miocene age with a thickness of up to 500 meters in the eastern part. The breccia member of the Cantayan Formation (Tmcb) consists of breccia with andesite-basalt and coral limestone fragments, and sandstone inserts in the upper part, with a thickness of up to 1700 meters and is of Middle Miocene age. The limestone members of the Bojongmanik Formation (Tmbl) consist of mollusk-bearing limestones that form lenses within the Bojongmanik Formation, dating to the Middle Miocene. The Bojongmanik Formation (Tmb) consists of sandstone, pumice tuff, limestone, and mudstone, approximately 550 meters thick and estimated to be Middle Miocene in age. Bogor Regency has several volcanic rock formations formed during the Quaternary Period, including the volcanic rocks of Mount Salak, with examples of basaltic andesite with pyroxene (Qvsl), tuff breccia and lapilli with weathered textures (Qvsb), and sandy pumice tuff (Qvst). The volcanic rocks of Mount Pangrango are characterized by younger, andesite-composed deposits (Qvpy), as well as older deposits, such as andesite-basalt with oligoclase-andesine (Qvpo). The volcanic rocks of Mount Gede are composed of tuffaceous breccia (Qvg) and numerous lava flows, such as the young lava flow (Qvgy) and the basaltic lava flow of Mount Gegerbentang (Qvba). All Quaternary volcanic rocks are scattered along the western side of Bogor Regency, and a little to the south, such as the volcanic rocks of Mount Gede. This type of volcanic rock is an important parameter because the hydrothermal mineralization process is closely related to volcanic activity. This is also an initial parameter in determining the research location, as the volcanic area created by the Sunda Arc offers the presence of valuable metal minerals and has the potential for epithermal gold because of the many active volcanoes that present the magmatic process where gold minerals are formed.

Methodology

The research began with a literature review of previous studies to obtain theoretical information and appropriate methods, particularly regarding the use of satellite imagery. The results of this literature review used a volcanic arc as the primary criterion in determining the research location. The presence of a volcanic arc indicates high magmatic activity, and Bogor Regency is part of the Sunda Arc. Therefore, the research location was determined in Bogor Regency. This was followed by the primary data collection stage, namely Digital Elevation Model (DEM) radar imagery, Landsat 9 OLI/TIRS C1 L1 multispectral imagery, Aster Level 1TV3 imagery, and remote sensing geological maps of Bogor, along with other supporting maps.

The data processing process began with lineament extraction using DEM data to obtain lineament density information as a parameter for determining potential alteration zones. This process was carried out using PCI Geomatica 2014 software. Next, image data processing began with Landsat 9 imagery, which first underwent preprocessing, including radiometric and atmospheric corrections. Pre-processed data was processed using the Sabin's Ratio method, as it can identify alteration minerals, oxide minerals, and hydroxides of iron, clay, carbonate minerals, and ferromagnessian minerals. This processing was performed using Arcmap and Envi software. Satellite imagery processing continued with pre-processing of the Aster imagery, which served as supporting information for the location of potential hydrothermal alteration zones using the Directed Principal Component Analysis (DPCA) method. The output of the DPCA method was argillic and propylitic alteration types, identifying the presence of chlorite and smectite-illite surface minerals.

The data obtained in the above stage was then analyzed by overlaying the three data sets: lineaments, Landsat 9 imagery using the Sabin's Ratio, and the distribution of potential argillic and propylitic alteration zones from the Aster imagery. Determining the potential for hydrothermal alteration zones is based on the presence of the three data points above at the same location. Zones with only one of the parameters are declared as unvalidated hydrothermal alteration potential zones, while zones with all three parameters are output as a hydrothermal alteration potential zone map in Bogor Regency. Subsequently, the potential alteration zones, lineament data, geological structures obtained from geological maps, and lithological conditions are analyzed using the Weight of Evidence (WOE) method.

The WOE method takes into account previously obtained parameters or data. The output of the WOE analysis is an Association Map of Geological Conditions to Gold Deposits, an Association Map of Potential Hydrothermal Alteration Zones to Gold Deposits, and a Lithological Association Map to Gold Deposits. Next, the gold potential level is determined using a selection attribute (query) technique, with outputs of three levels of gold potential: high, medium, and low. This results in a Map of Potential Epithermal Gold Mineralization Areas in Bogor Regency.

Results and Discussion

a. Lineament Density

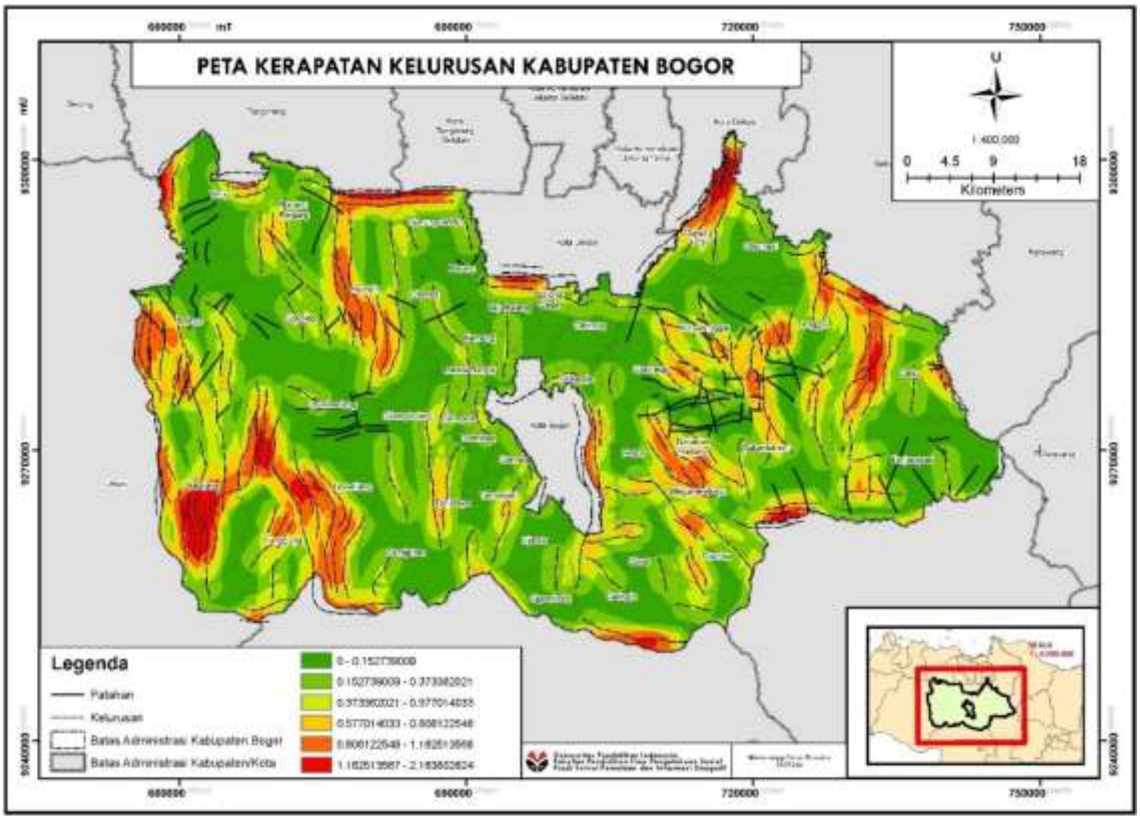

Figure 2. Lineament Density Map of Bogor Regency

This study used USGS Digital Elevation Model (DEM) data to extract lineaments in Bogor Regency. Lineaments are a parameter for determining alteration zones, as their presence indicates permeable zones and media for hydrothermal fluid flow from the reservoir to the surface. Areas with high lineament density are dominated on both the west and east sides, with the western side of Sukajaya, Nanggung, Leuwiliang, Jasinga, and Rumpin sub-districts. Sub-districts with high lineament density are Cariu, Gunung Putri, Kelapanunggal, Babakan Madang, Sukamakmur, and Cisarua.

b. Results of the Potential Alteration Zone Map Using Sabin's Ratio and Crostal's Analysis

1. Alteration Zone Map Using Sabin's Ratio

The results of the Sabin ratio composite bands show several minerals such as minerals with iron oxide, clay and hydroxyl, iron minerals, and altered minerals. Each of these minerals produces a different color, iron oxide with pink to purple, spread almost throughout Bogor Regency which is very thick in the districts of Bojong Gede, Sukaraja, Cisarua, Ciomas, Parung to Parung Panjang. Clay and green hydroxyl minerals are spread in the districts of Tenjo, Cigudeg, Jasinga, Sukajaya, Nanggung, the southern side of Pamijahan, Klapanunggal, Cariu and Tanjungsari. Bluish ferrous minerals are spread in the districts of

Tenjo, Jasinga and Sukajaya. The hydrothermal alteration area is characterized by yellow to orange colors and the association of green with pink. The distribution of alteration areas is focused on the eastern and western parts of Bogor Regency, namely in the districts of Jasinga, Sukajaya, Nanggung, Leuwisadeng, Leuwiliang, Tenjo, Parung Panjang, Cariu, Tanjungsari, and Jonggol, yellowish colors are commonly found close to purple and green. Therefore, to help interpret the image, several composite band compositions are needed.

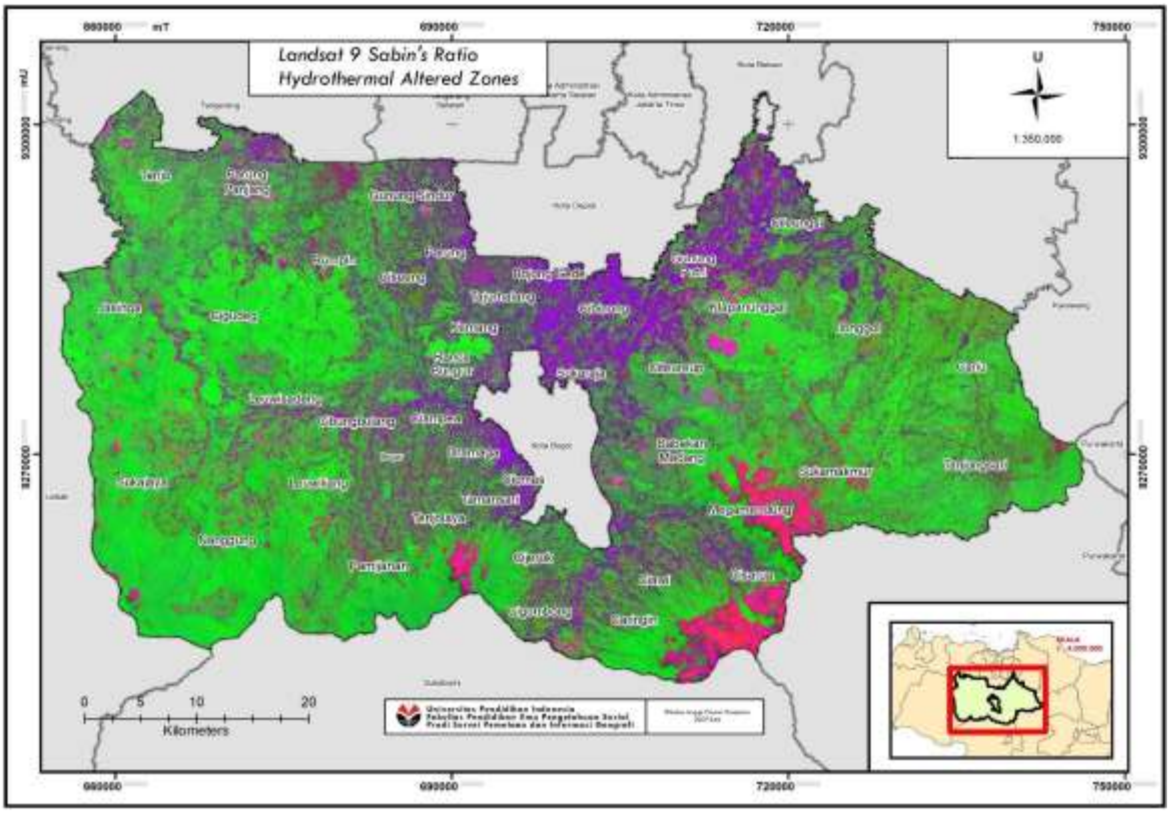

Figure 3. RGB Image Composite Using Sabin's Ratio

2. Crostal's Analysis

The application of PCA in Table 1 for iron oxide minerals shows that PC4 has a positive value for band 2 (0.720) and negative for band 4 (-0.682), these two bands have the largest difference values in the PC analysis and have significant large positive and negative values. Thus, a negative value in band 4 indicates a pixel with the presence of dark-colored iron oxide minerals or dark pixels. Meanwhile, the presence of hydroxyl minerals in PCA bands 2, 5, 6 and 7 Table 2 is found in PC4 with band 6 having a positive value (0.670) and band 7 (-0.697) based on negative and positive eigenvector analysis. With the contribution of band 7 having a negative value to search for hydroxyl marked by dark pixels.

Table 1. Principal Component of Landsat 9 Imagery in Bands 2, 4, 5 and 6 for Identification of Iron Oxide Minerals

	PC1	PC2	PC3	PC4
BAND 2	0.479	-0.354	-0.356	**0.720**
BAND 4	0.538	-0.449	-0.211	**-0.682**
BAND 5	0.523	0.820	-0.227	-0.057
BAND 6	0.456	-0.039	0.881	0.113
Percent of EigenValues	**81.876**	**14.180**	**3.820**	**0.123**

Table 2. Principal Component of Landsat 9 Imagery in Bands 2, 5, 6 and 7 for Hydroxyl Mineral Identification

	PC1	PC2	PC3	PC4
BAND 2	0.494	-0.285	-0.810	0.133
BAND 5	0.576	0.787	0.039	-0.218
BAND 6	0.510	-0.212	0.496	**0.670**
BAND 7	0.404	-0.505	0.310	**-0.697**
Percent of EigenValues	**79.042**	**15.976**	**4.742**	**0.240**

The crostal method was used as supporting information in determining potential hydrothermal alteration zones in this study. Crostal essentially consists of a composite of iron-oxide, hydroxyl+iron-oxide, and hydroxyl bands. The PCA inputs used were bands 2, 4, 5, and 6 to enhance the spectral response of minerals containing iron oxide, and bands 2, 5, 6, and 7 to enhance the spectral response of minerals containing hydroxyl (OH). Image enhancement for minerals containing iron oxide was performed because iron oxide is a component in alteration zones associated with sulfide deposits and can be identified through a band ratio of 4/2 as a PCA input. Meanwhile, minerals containing hydroxyl, such as chlorite, kaolinite, and sericite, are frequently found in geological environments associated with gold deposits and in hydrothermal systems.

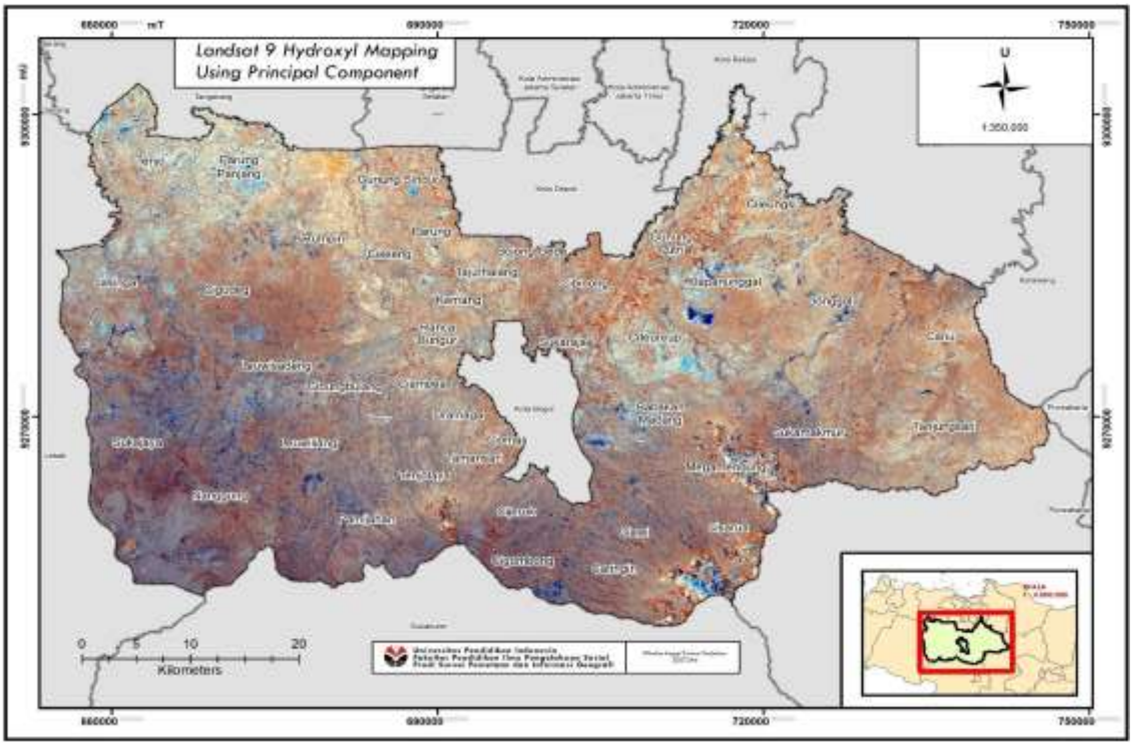

Figure 4: Distribution Map of Iron-oxide, Hydroxyl and Hydrothermal Alteration Minerals.

c. The Distribution of Potential Hydrothermal Alteration Zones in Bogor Regency

Principal Component Analysis to find hydrothermal alteration zones in this study uses a combination of Crostal composite bands, namely iron-oxide, hydroxyl + iron-oxide, hydroxyl. The RGB results depict yellow to orange colors identified as minerals containing hydroxyl, bluish to light blue colors are iron-oxides, and alteration zones with bright or white colors. Crostal in the study suggested involving many other factors in delineating altered mineral zones marked by bright white colors. Bright white colors are often mistaken for bright blue, cloud object reflections, or faded yellow. In this study, bright white colors are often seen adjacent to blue, and are often found at the foot of Mount Gede and Mount Salak volcanoes. However, the author did not delineate the area as one of the potential zones of altered minerals because there are cloud objects that allow the presence of anomalies. Crostal himself analyzed the DPCA results when the iron oxide, hydroxyl+iron oxide, hydroxyl (H, H+F, F) composite band had been performed, because direct identification using greyscale DPCA results increased anomalies during interpretation, because the interpreter was only able to assess from two levels of black-white tones.

Figure 5. Map of the Distribution of Potential Hydrothermal Alteration Zones in Bogor Regency

Conclusion and Recommendation

Based on the analysis results, the hydrothermal alteration zone in Bogor Regency is generally concentrated in the western (Sukajaya, Nanggung, Leuwiliang, Jasinga, Tenjo, Parung Panjang) and eastern (Cariu, Tanjungsari, Jonggol, Klapanunggal, Babakan Madang, Sukamakmur, Cisarua) parts, which are characterized by high lineament density as a path of hydrothermal fluid movement and the distribution of iron oxide, clay, and hydroxyl minerals from Sabin, PCA, and Crostal ratio analysis results; this condition indicates the potential existence of a hydrothermal system associated with gold mineralization, although the interpretation still needs to be validated through field surveys and geochemical tests to ensure the presence of mineralization and avoid bias due to image anomalies such as cloud influences.

References

Franandy, D., & Isniarno, N. (2023). Aplikasi Penginderaan Jauh (Remote Sensing) untuk Identifikasi Zona Potensi Keberadaan Emas Epitermal PT DEF di Kecamatan Simpenan Kabupaten Sukabumi, Provinsi Jawa Barat. *In Bandung Conference Series: Mining Engineering*, (Vol. 3, No. 1, pp. 263-269).

Rosana, F., Denni, W., & Wawan, K. (2011). *Potensi Sumberdaya Mineral Jawa Barat: Menuju Pembangunan Jawa Barat yang Berkelanjutan.* Pusat Sumberdaya Geologi, Fakultas Teknik Geologi UNPAD, Pusat Sumberdaya Geologi, Pusat Survey Geologi.

Zafar, N., Yudhistira, S., & Hoppy, A. (2019). Peningkatan Recovery Emas Di Carbon in Leach Plant Pt. Antam Tbk Unit Bisnis Pertambangan Emas Pongkor, Jawa Barat (Studi Kasus Kadar Bijih 3,5 – 4,5 Gpt Di Plant 1). *Prosiding Temu Profesi Tahunan PERHAPI*, 1(1): 49–58.